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Human Kinetics
COMMENTARY

The Parameters of the Intended Movement Determine the Capacity to Correct the Forthcoming Movement

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Arm movements are among the most frequent and important of the human voluntary motor repertoire. Many of these movements are directed toward visual objects. Accordingly, a substantial amount of research has been devoted to uncovering i) the cascade of neural processes allowing to convert the visual target position into arm motor commands and ii) the processes allowing to modify these motor commands when the produced movements differ from the intended movements (due for instance to planning errors or external perturbations). The opinion article by Smeets and colleagues focuses on these latter processes. Using as a backdrop the different stages of information processing identified by Donders (1868, 1969), the authors provide a thorough and comprehensive overview of the contexts that may favor or hinder the occurrence of fast corrections during visually guided hand movements.

Smeets et al. convincingly demonstrate that the constraints of the movements are factors that markedly influence the latency of the movement corrections. For instance, they report evidence from the literature that the latencies of the corrections depend of whether the hand is in the vicinity of the target (Liu & Todorov, 2007; Oostwoud Wijdenes et al., 2011) and also of the direction of the correction with respect to the stimulus that appears in the visual field (i.e., toward or away from the stimulus, Day & Lyon, 2000; Johnson et al., 2002). Here, we would like to draw attention on movement constraints that Smeets and colleagues have overlooked and which have strong effects on the time required to correct ongoing hand movements: the direction and the amplitude of the movement.

We have indeed accumulated evidences from previous studies that the online control of the movement weakens when participants have to decelerate the arm to stop the hand on the target compared with a situation where the amplitude requirements are relaxed, i.e., when only movement direction has to be controlled. The first clues that controlling movement amplitude hampers the control of movement direction arose from the contrasting capacity that had participants to modify their planned hand trajectory in response to a sudden target displacement in two separate studies (Blouin et al., 1995a,b). The goal of these experiments were different. In a study that we conducted in collaboration with Bruce Bridgeman at the University of California at Santa Cruz (Blouin et al., 1995a), we tested whether the perceived

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stability of the environment was enhanced when there was a combination of eye and visually open-loop hand movements toward a target displaced during eye movements (i.e., saccadic suppression of retinal input). In the other experiment (Blouin et al., 1995b), we tested whether the corrections observed by Pélisson et al. (1986) and Goodale et al. (1986) during movements produced at moderate speed (i.e., 500–650 ms) when the target was displaced during the saccade could be observed when movements were performed with greater speeds. Despite the fact that they had different research goals, both studies used very similar procedures: i) the targets displacements occurred on randomly presented trials, ii) the targets could be moved to the right or to the left from their initial position, thus requiring a change of movement direction only, iii) the targets were displaced during the saccade produced in their direction, less than 110 ms before reaching movements onsets, and iv) participants had to produce extremely fast movements (mean movement time: 189 ms and 208 ms in Blouin et al. 1995a and Blouin et al. 1995b, respectively). The key methodological difference between these studies was the presence/absence of movement amplitude constraints. Indeed, in the former study, the participants were required to hit at high speed the screen on which the target was presented and had therefore only the direction of their movements to control. In the latter study, the participants had to stop their hand under a target suspended in the air in front of them. Therefore, in this case, the participants had to control both the direction and amplitude of their movements. Surprisingly, a striking difference resulted from these studies between the capacities of the participants to change the direction of their fast movements to reach the new target position. Without amplitude constraint, the participants compensated almost entirely for the change of target direction. Conversely, when the reaching movements had amplitude constraints, the participants have proved incapable to change the direction of their movements. They reached the initial position of the target.

We also observed similar marked effect of the amplitude constraints on the possibility to modify the direction of ongoing movements when unconscious 5-cm shifts of the hand visual feedback occurred near movement onset, during the saccadic suppression of retinal input (Sarlegna and Blouin, 2010). The impact of the amplitude constraints on the control of movement direction can be seen in Figure 1. The figure shows top views of representative spatial paths of the hand (i.e., not of the visual feedback of the hand) when the participant had to control both the direction and amplitude of the movement (Figure 1a) or only its direction (Figure 1b). When the participant had to stop the hand at a virtual target which appeared as being suspended in front of him, he first stopped the hand near the target before changing hand direction on the basis of the biased hand visual feedback. This behavior clearly contrasted with the earlier online correction of movement direction when the participant was instructed to pass through the target until full arm extension (i.e., no control of movement amplitude). On average, in this condition, the adjustments of movement direction was ~50% of the shift of hand visual feedback. The magnitude of the corrections was therefore smaller than that observed after a shift of the target position (a phenomenon also observed in Sarlegna et al., 2003). However, it was close to that reported in a previous study where participants compensated for about half of the unconsciously perceived shift in hand visual feedback, irrespectively of the magnitude of the shifts (i.e., 1–4 cm, Sarlegna et al., 2004). This latter result suggests that enough time was available for correcting movement direction and that the spatio-temporal constraints of the task were not responsible for the limited use of hand visual feedback. Rather, the smaller adjustments of hand direction found during biased hand visual feedback compared with conditions with target displacements suggest that, for fast reaching movements (movement duration being 300–350 ms in these studies), online control of movement direction not only involves hand visual feedback but also proprioception of the limb. According to this scheme, visual and proprioceptive information would be integrated with similar respective weights to control the direction of the (rapid) movement (see also Sober and Sabes, 2005).

The question regarding the mechanisms responsible for the decreased ability to produce fast directional corrections when participants actively decelerate and stop the hand at the target does find answer in Smeets and colleague's opinion paper. Where our opinion might differ from the authors' view (see Oostwoud Wijdenes et al., 2013) is that we believe that these observations can be well explained in the framework of the vectorial coding model of the movements. According to this model, the brain would compute the hand-target vector and then plan the motor commands according to the direction and the amplitude of this vector (Davare et al. 2012; Favilla et al., 1990; Ghez et al. 1989; Krakauer et al., 2000; Messier and Kalaska 2000; Rossetti et al. 1995). Importantly, several studies have shown that movement direction has to be specified before movement onset or very early in the trajectory (Blouin et al. 1993; Fleury et al., 1994; Paulignan et al., 1991; Ghez et al., 1989; van Sonderen et al., 1988). Moreover, the amount of time taken to trigger a movement is shorter than the time required to completely specify response amplitude (Favilla et al., 1990; Ghez et al., 1989). In this light, it appears plausible that after the onset of a movement that has directional and amplitude requirements, the control of amplitude is emphasized, hampering the online control of movement direction. Conversely, relaxing the amplitude constraints would enable

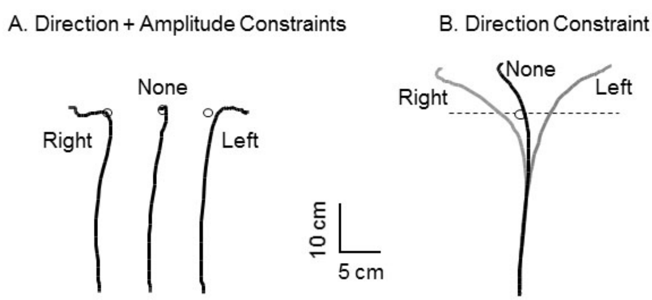

Figure 1 — Top view of representative spatial paths of the hand when a 5 cm shift of hand visual feedback occurred during the saccade toward the virtual image of the target. The direction of the bias in the hand visual feedback is indicated beside each hand trajectory. A. Virtually no directional correction was observed before the hand stopped at the target when the participant had to control both the direction and the amplitude of the movement. B. Large and early changes of the trajectory direction appeared when the participant had to pass through the virtual target until full arm extension (i.e., no amplitude requirement). The horizontal plane indicates the target plane. Figure adapted from Sarlegna and Blouin (2010) with the permission of the Association for Research in Vision and Ophthalmology.

the continuous the control of hand direction during movement execution. In this perspective, the control of direction and amplitude would only interfere in the case of very fast hand movements and when the target object, or its supporting surface, cannot be used to decelerate the hand.

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